Appendix A

Information Technology Trends and the Value-Creation Potential of Networks

Information technology and the "networks" they enable play a fundamental role in enabling the network-centric enterprise. Consequently, understanding the underlying trends that govern technology and influence the value-creation potential of networks is important to understanding the potential power of network-centric operations.

The basic building block of a network-centric enterprise is the entity. Entities work both individually and collectively to create the value generated by network-centric operations. The nature of their interactions is enabled or constrained by the characteristics of the technology that is available to these entities and which governs the interactions among them. For example, if entities can only interact via mail, then the nature of their information exchanges will differ significantly from entities that can instantly interact in a multi-media environment (e.g., video teleconferencing).

Technologies that are associated with linking entities include: telephones, radios, fax machines, televisions, computers, and personal digital assistants. Networking systems provide the functional capability to direct information from one node to another. In most large networks, large numbers of networking devices are employed to direct information among nodes. Links provide transmission paths among networking devices and nodes, as well as gateways to other networks.

With modern voice networks, nodes consist of telephones. Optimized networking systems provide quality of service for voice traffic (e.g., PBX switches). Transmission mediums include wire line, fiber, and radio frequency.

With cable networks, nodes consist of cable boxes connected to customers' televisions and signal broadcasting centers providing signals that are distributed over the cable network. Until recently, cable networks were designed principally to operate in half-duplex mode; that is, signals travel in only one direction—from the broadcast node to the set-top box.

With modern data networks, nodes are digital and networking systems (e.g., routers, Asynchronous Transfer Mode (ATM) switches) are optimized for data traffic. As with voice networks, transmission lines include wire line, fiber, or radio frequency.

Military operations employ commercial information technologies, as well as military specific information technologies. In general, the primary difference between the networks used by deployed warfighters and the networks used by non-mobile entities is the characteristics of the links. The primary transmission path for the deployed warfighter is radio frequency communications enabled by radio, data link, or satellite. Furthermore, military operations typically require special link features, such as security and anti-jam, which to date have not been priorities for commercial users.

There are a number of fundamental business and technology trends that are shaping the future of networks, the nature of the nodes that are connected to networks, and the future of network-centric operations.

Moore's Law—2x Every 18 Months

Moore's Law describes the principle dynamic of innovation in the semiconductor fabrication market. In 1965, Gordon E. Moore, then R&D Director at Fairchild Semiconductor and presently Chairman Emeritus of Intel Corporation, observed that semiconductor manufacturers had been doubling the density of components per integrated circuit at regular intervals from 1959 to 1964. Furthermore, he asserted (based on three data points!) that this trend was poised to continue for the foreseeable future (at least the next 10 years). Upon reexamination by Moore in 1975, the regular interval turned out to be approximately 18 months. The net result is that for the past 45 years the performance of computer chips has doubled approximately every 18 months as a direct result of increasing component density. It is worth noting that the performance of dynamic Random Access Memory (dRAM) chips has increased at a faster rate than computer chips. Multiple factors have interacted to enable this remarkable run, which to a large degree is the direct result of the innovation and leadership of a wide range of companies. These companies range from the chip producers themselves (i.e., Intel, AMD, Motorola, Texas Instruments), to the companies that design and produce the semiconductor fabrication equipment used by the chip producers (i.e., Applied Materials, Lam Research, Novellus Systems).[1]

The limits to continued progress in increasing the density of semiconductor processing chips based on silicon technology are defined by physics. Scientists at Bell Laboratories recently identified that fundamental limits to chip density will be approached in 2012, when semiconductor gate sizes reach atomic limits.[2]

The same technology trends which have enabled the performance-cost ratio for personal computers to double approximately every 18 months have also enabled relatively small, powerful chips to be deployed in a wide variety of devices, such as personal digital assistants (PDAs). The net result is that the metric for measuring the degree of adoption of computer technology has been redefined several times from the percentage of households that own a computer to the number of computers per household to the number of computing devices per individual. In addition a new metric, percent of households connected to the Internet, has come into use. Analogous trends are being played out in warfare as we make the shift to network-centric operations.

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[1] Michael Murphy, *Every Investors Guide to High-Tech Stocks and Mutual Funds* (New York, Broadway Books, 1997), 49-74.

[2] David A. Muller, et al, "The Electronic Structure at the Atomic Scale of Ultrathin Gate Oxides," *Nature*, Volume 399, June 24, 1999, 758-761.

Transmission Capacity—2x Every 12 Months

Currently, the primary backbone of advanced networks (both voice and data) is fiber optic cable. Recent and ongoing developments in the field of optical communications have resulted in the doubling of the transmission capacity of fiber optic cable every 12 months. The core technology behind this increased performance is dense wave division multiplexing that enables multiple wavelengths of light to be transmitted simultaneously over a single cable. Four key enabling technologies are at the core of the performance increases in dense wave division multiplexing:

1) sources of multiple wavelengths;
2) tunable optical filters;
3) wavelength multiplexers/demultiplexers; and
4) multiwavelength optical amplifiers.[3]

This performance trend in fiber optical communications is key to enabling the significant capacity increase of the Internet. It is also the source of the assertion made by many that in the near future, terrestrial bandwidth will be a commodity.[4] In addition, companies such as Teledesic are pursuing efforts to launch large constellations of satellites to provide high capacity bandwidth worldwide over radio frequency.

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[3] Alan E. Willner, "Mining the Optical Bandwidth for a Tera Bit Per Second," *IEEE Spectrum,* April 1997, 32-41.

[4] Seth Schiesel, "Jumping Off the Bandwidth Wagon: Long Distance Carriers Regroup," *The New York Times* (July 3, 1999, Section 3: Money & Business), 1, 10, 11.

Confluence of Trends—Network-Centric Computing

The consequences of these mutually reinforcing trends have been profound. The combination of increasing performance and cost suppression has resulted in the widespread adoption of computers in business and in the home which, when combined with trends in communications, has set the stage for network-centric computing and network-centric operations. The combination of digital communications capabilities and breakthroughs in software technology in the form of Web browsers and servers has combined to enable information interactions among entities of virtually any size that can be connected to the Internet. The net result is referred to by some as the social-technological phenomenon, the "Internet Tsunami."

Metcalfe's Law

Metcalfe's Law, named after Robert Metcalfe, inventor of the ethernet protocol technology and founder of 3Com, has emerged as a central metaphor for the Internet Age.[5] Metcalfe's Law observes that although the cost of deploying a network increases linearly with the number of nodes in the network, the *potential* value of a network increases (scales) as a function of the square of the number of nodes that are connected by the network.

Business Trends—Convergence of Voice and Data

The confluence of these technology trends is creating new business opportunities and outmoding existing business models in the communications and

[5] George Gilder's Telecosm, "Metcalfe's Law and Legacy," *Forbes ASAP*, September 13, 1993, 158-166.

computing sectors. In the computing sector, the dramatic increase in computer performance enabled by Moore's Law has resulted in the introduction of entry-level systems at the $500-price point. As a result of this trend, profit margins for entry-level personal computers have been significantly reduced. Associated with this trend is an emerging business strategy that calls for personal computers to be given away virtually for free as loss leaders by Internet Service Providers. A consequence of these developments is the emergence of data traffic (vice voice) as the primary method of information transmission. Data traffic over the Internet is currently doubling every 7.5 months, while voice traffic over the Internet core is doubling every 4 months.[6] Consequently, the transmission of data is primary organizing logic for 21st-century networks. Networks are currently being, and will continue to be, optimized to simultaneously handle voice, data, and video over digital networks.

Implications of Metcalfe's Law

The discussion that follows explores the underlying logic behind Metcalfe's Law, the meaning of "value," and the need for extending the law with corollaries that account for networks with different performance attributes.

Much of the confusion over the meaning of Metcalfe's Law has to do with the definition of "value." The number of *potential* first order information interactions enabled by a network with N entities is computed as Nx(N-1).

[6] Rich Roca, "AT&T Bell Labs Presentation on Information Technology Trends to GovTechNet '99," Washington, DC, June 16, 1999.

Consequently, as will be clear from the derivation that follows, Metcalfe's Law asserts that if the metric for measuring value is the number of potential information interactions enabled, then for large N this value increases exponentially as N^2.

However, this approach to measuring value has its problems. It assumes that:

1) there is real potential in all interactions;
2) all interactions have positive value;
3) all interactions have equal value; and
4) the sum of a pair of wise interactions reflect the overall value.

In addition, it does not account for the nature of the simultaneous interactions among multiple entities.

We believe that the *potential* for a network to *create value* is a function of the type of the information interactions enabled by the network and the value-creation logic being employed by the users of the network. Thus, *establishing a direct relationship between information and value is at the heart of value creation in the Information Age and is fundamental to understanding the power of network-centric operations.* In addition, we believe that:

1) most potential interactions will never take place;
2) the value of interactions will differ significantly;
3) there will be islands of dense and intense interactions that will dominate the value function;

4) the value of a given interaction will be a function of the content, quality, and timeliness of the interaction; and
5) N-way interactions will be the most significant in value creation.

The following examples provide useful insights into the derivation of the value scaling properties of networks, as well as the need for associating with a network the concept of value-creation logic and user-value preferences (sometimes referred to as a utility function).

The largest networks (in terms of number of entities) that exist today are telecommunications networks. These networks represent hundreds of billions of dollars in investments made over a period of decades by telephone companies. The existence of these networks paved the way for the Internet because it provided the initial backbone of the Internet, as well as the "last mile" that connected the majority of customers to Internet service providers.

Telephone networks had been deployed widely when the fax machine, representing a new type of interaction, was first introduced.[7] When the first fax machines were installed they had limited value because there were very few other fax machines to connect to and to exchange information with.

As the size of the installed base of fax machines increased, the potential number of information

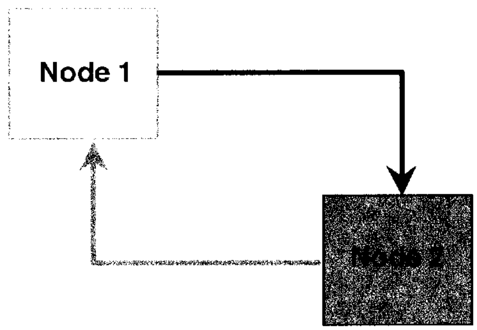
[7] Valerie-Anne Giscard d'Estang and Mark Young, *Inventions and Discoveries 1993,* New York, Facts on File, 1993, 198.

interactions among fax machines increased exponentially. The following very simple example of a network of entities that interact via fax demonstrates how the number of potential information interactions in a network is computed.

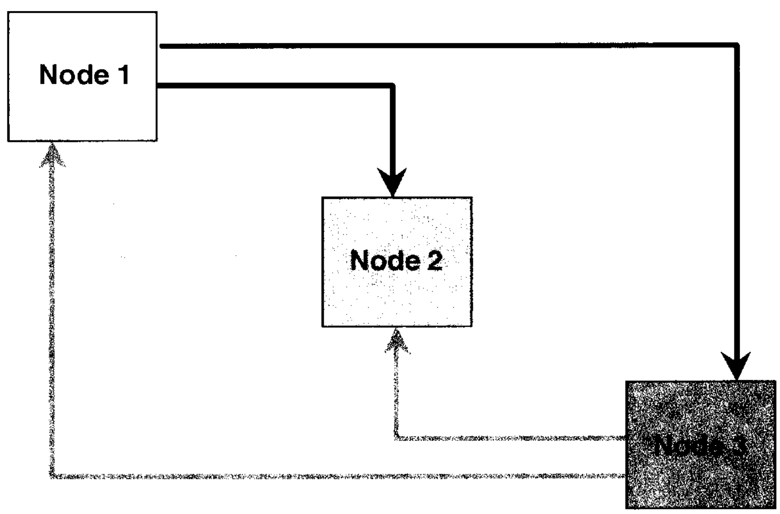
One fax machine has zero value to a user because it cannot transmit or send information to any other fax machines. As soon as a second fax machine is added, two information interactions are enabled. Fax 1 can fax to Fax 2, and Fax 2 can fax to Fax 1. These interactions are portrayed in Figure A-1(a). Once Fax 3 is added, we observe that the number of potential information interactions increases significantly, as portrayed in Figure A-1(b). The total number of interactions is six.

We observe that in general, if a network contains "N" entities, every entity can initiate "N-1" information interactions. Therefore the total number of potential value-creating interactions is: $Nx(N-1)$ or N^2–N. For large values of N, the potential number of value-creating interactions in a network scales with N^2 or "N squared." Thus, Metcalfe's Law asserts that to the first order, the potential value of a network is a function of the number of potential information interactions between networked entities.

However, this is a gross oversimplification because, as we observe above, not all interactions are of equal value. We need to quantify user value as a function of the type of information interactions that are enabled (the content, quality, and timeliness of information exchanged), network-enabled, value-creation logic, and user-value preferences.



(a) Network with 2 Nodes (N=2)
Number of Information Interactions=2x1=2



(b) Network with 3 Nodes (N=3)
Number of Information Interactions=3x2=6

Figure A-1. Entity Interactions

For example, if we applied the scaling logic of Metcalfe's Law to a network of e-mail-enabled entities, it would yield the same results as when applied to a network of fax-enabled entities. Clearly that would be incorrect, for the potential value of a network of "N" e-mail clients is greater than the potential value of a network of "N" fax machines as explained below. We can gain insight into the difference in value by comparing the key attributes of various information technologies, using the diagram portrayed in Figure A-2.

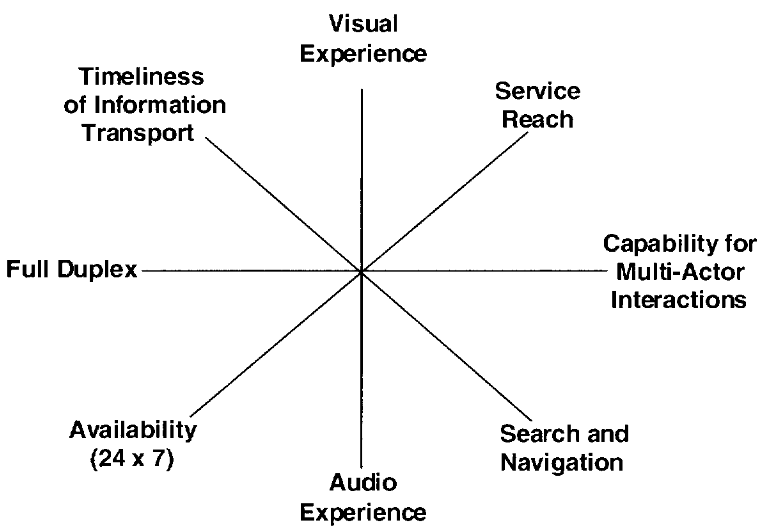


Figure A-2. Attributes of Information Technologies

As a point of departure, we can examine the key attributes of traditional mail, a very primitive "information technology," portrayed in Figure A-3. Mail can be sent and delivered to any address on the planet. In addition, large amounts of information, in customized format, can be sent by mail. Furthermore, we can observe that value to the "user" of mail service can be increased by decreasing the delivery time, as well as providing in-transit visibility (and return receipts).

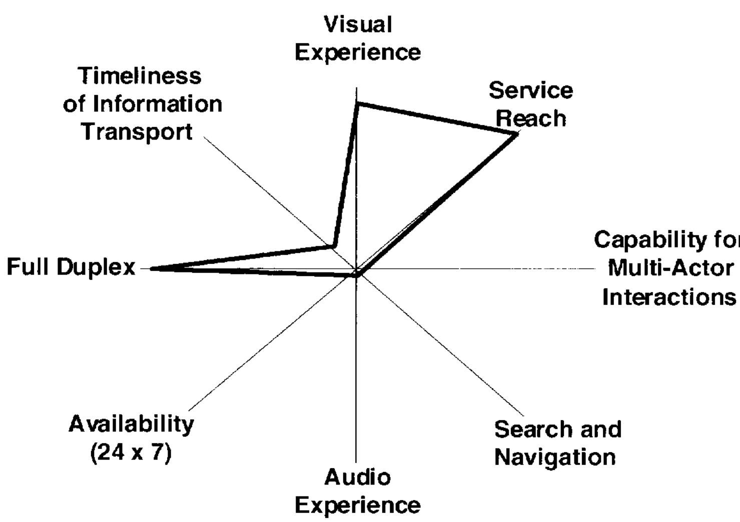


Figure A-3. Traditional Mail

Fax machines enable information "stored" in paper form to be digitized and transmitted in near-real time, resulting in drastically reduced delivery time compared to traditional mail, as shown in Figure A-4. However, faxes only can be sent to other fax machines, while traditional mail can be delivered to any "address" on the planet.

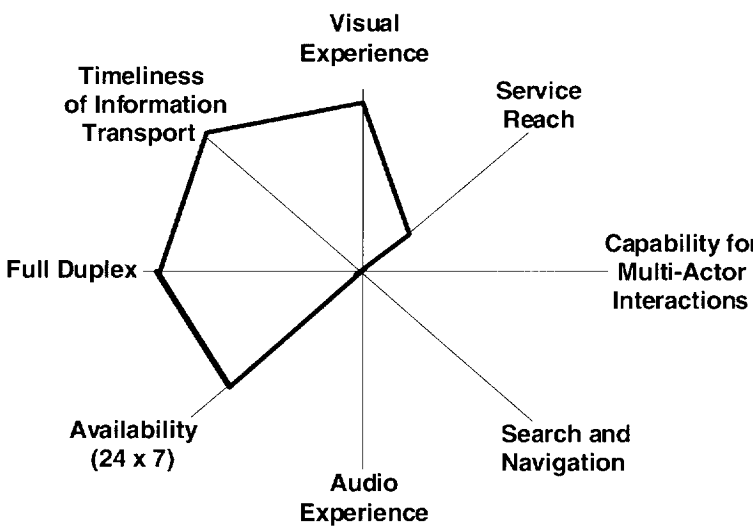


Figure A-4. Fax Machines

E-mail technology has some of same attributes as fax technology, as well as additional attributes. With e-mail, the potential exists for transmitting digital attachments, such as text files, graphic files, and audio files, as shown in Figure A-5. E-mail also allows messages to be stored electronically and easily referenced.

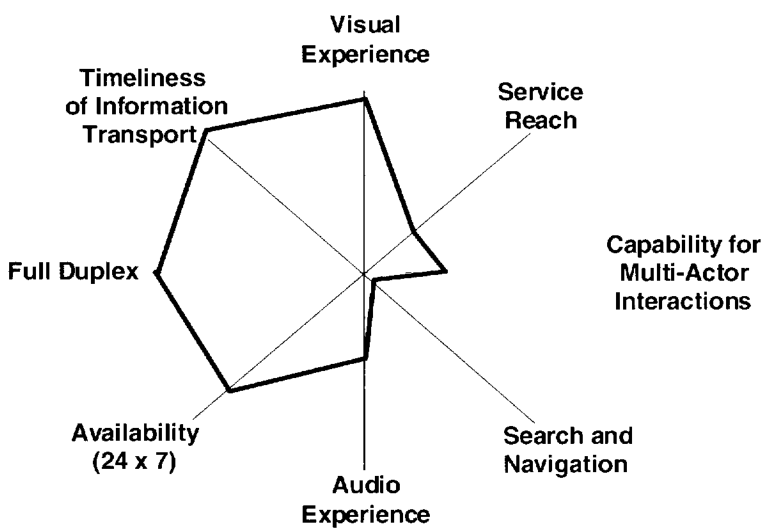


Figure A-5. E-Mail

However, in examining attributes associated with Web technologies, we can observe that this information technology enables fundamentally new types of information interactions, as portrayed in Figure A-6. Perhaps the most significant attribute is search and navigation. This attribute enables users to search for potential sources of information (via key word searches), and then navigate information sources once they are found. The capability for multi-actor interactions refers to the capability to enable multi-actor interactions, such as chat rooms, virtual white boards, and "on-line auctions" (e.g., eBay). *The capabilities enabled by the Web represent an order of magnitude increase in the ability of humans to operate in the information domain.*

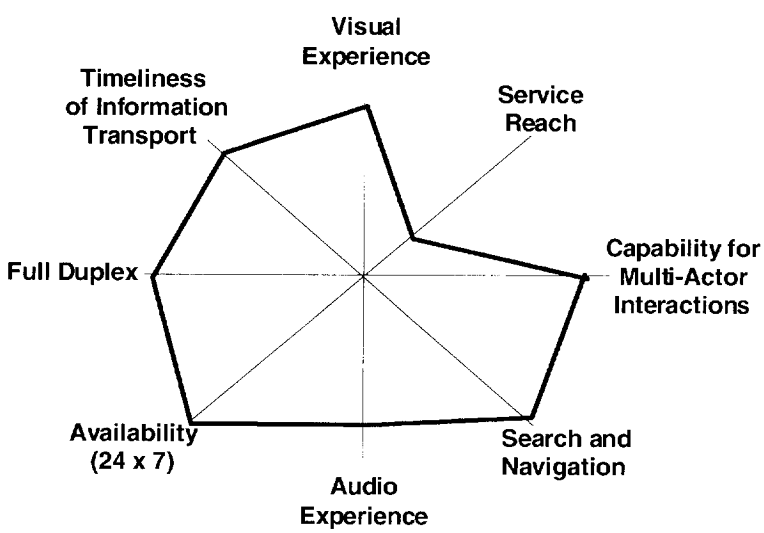


Figure A-6. World Wide Web

Clearly, the potential value of Web-enabled networked entities is greater than an equivalently sized network in which entities can interact via e-mail or fax. As was pointed out previously however, the value to the end user is a function of a user-value function, and a network-enabled, value-creation logic. Consequently, understanding the role that information interactions play in creating value (value-creation logic) is key to understanding the implications of Metcalfe's Law.

Now, given the complexity of the Internet and the potential for a large number of network-enabled, value-creation logics to be available to users, it becomes increasingly clear that it is virtually impossible to compute the "value" of a network to all end users or potential users. *However, it is possible for a single user, with a well-defined value metric, to estimate the potential value of the network to them as an individual user. Furthermore, it is also possible for the developers of Internet sites to identify the principle components of value for which customers may have a preference.*

Clearly, the process of computing value is complex. A useful approach is to recognize that attributes provide a basis for value, and that user preference, or utility, can be approximated as a weighing of attributes.

For example, consider the network-enabled, value-creation logic associated with on-line retailing for an Internet company such as Amazon.com. There are multiple potential attributes to the on-line experience, which are highlighted in Figure A-7, compared to traditional approaches. Individual customers will decide to participate in an on-line transaction to the extent that they place a "value" on these attributes. In some instances, individual attributes will be more or less important to the same customer.[8]

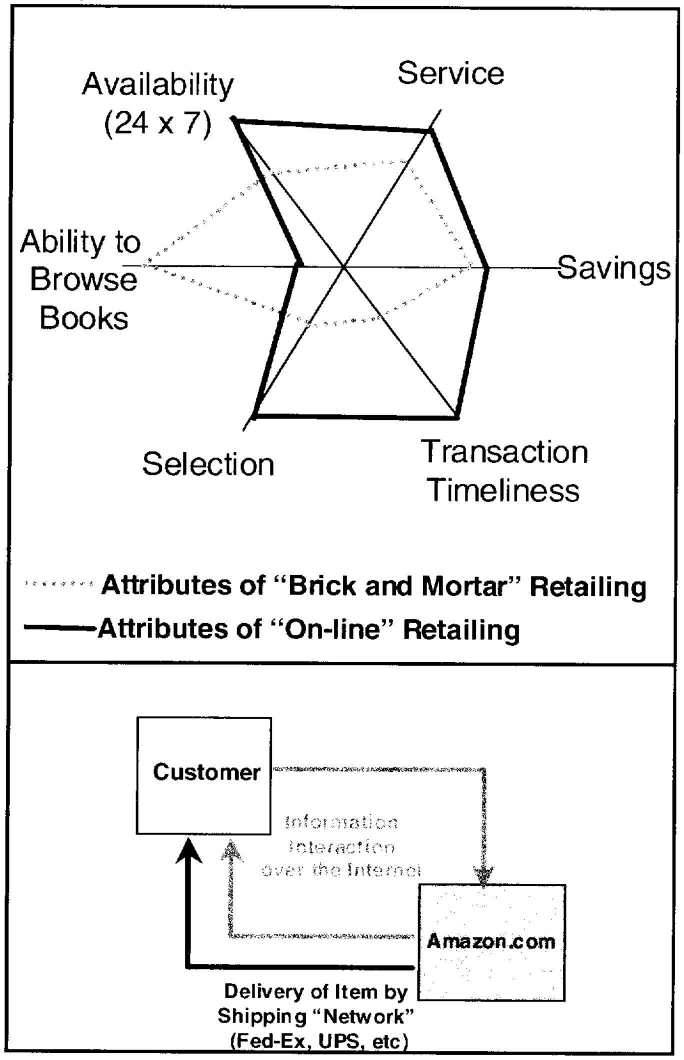


Figure A-7. Network-Centric Value Creation—On-line Retailing

[8] Leslie Walker, "Looking Beyond Books: Amazon's Bezos Sees Personalization as Key to Cyber-Stores' Future," *The Washington Post* (November 8, 1998, Section H: Business), 1, 14.

Similar trends hold with on-line stock trading, whose attributes are highlighted in Figure A-8. Now, as with on-line retailing, the value that an individual user will place on these attributes is a personal preference.

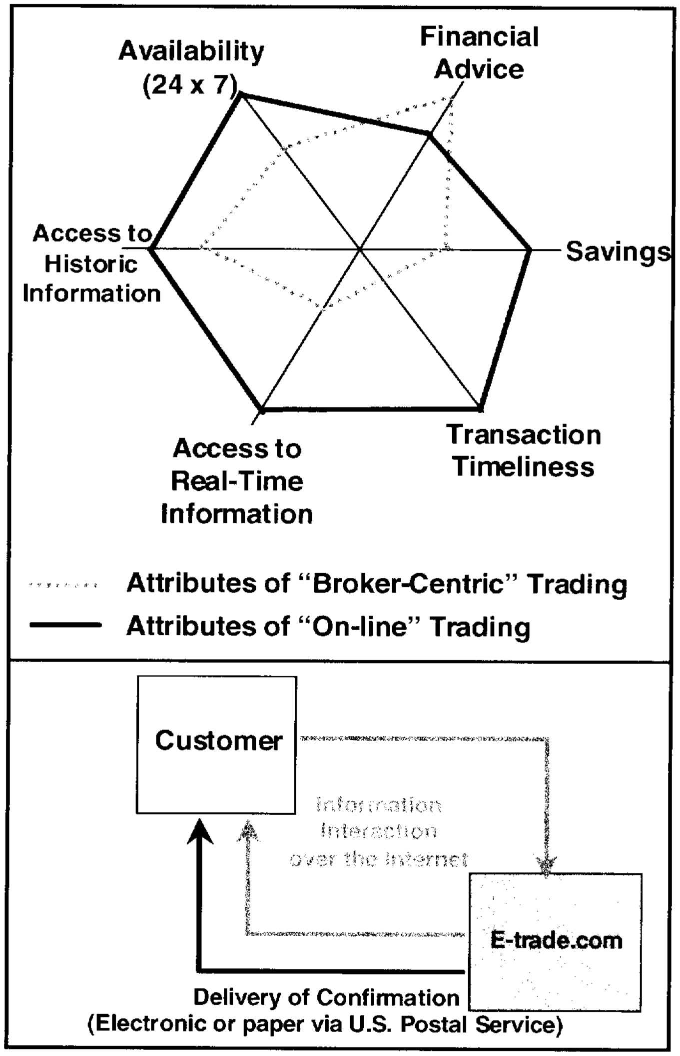


Figure A-8. Network-Centric Value Creation—On-line Trading

The key point here is to recognize that quantifying the value of a "network" requires both a value-creation logic and user-defined value preferences (value function). Consequently, in the domain of warfare, one should expect that similar logic would apply. Any measure of network-enabled combat power needs to have these two components: a value-creation logic and user-defined value preferences (value function).

The following examples of network-enabled (network-centric), value-creation logic in military operations provide insight into the sources of combat power associated with network-centric operations.

1) The networking of entities (sensors, deciders, actors) enables shared battlespace awareness. This shared awareness represents an improved position in the information domain.

2) High performance networking of sensors creates an improved position in the information domain by enabling sensor tasking and fusion, which decreases uncertainty associated with object state estimates: position, velocity, object identification (e.g., friendly, hostile).

3) Actors make decisions and "act" based on the content, quality, and timeliness of information in the information domain.

4) A position in the information domain is translated to combat power (measurable value) in the battlespace by actors and

decision makers. (Similar to the Internet, decisions made by actors are the source of value.)

5) Networking entities enables decision makers and actors to interact in new ways; in effect, to create new modes of operation. Self-synchronization is an example of a new, network-enabled mode of operation, or network-centric operation.

6) In addition, the networking of entities enables functions to be relocated, or reallocated, across the warfighting force.

In summary, the following can be said with respect to Metcalfe's Law:

> To first order, it describes the potential number of information interactions that are enabled by a network of "N" nodes.
>
> To second order, it provides insight into the fact that the "value" of a network to the users of the network is primarily a function of the interaction between:
>
> 1) content, quality, and timeliness of information interactions enabled by the network;
> 2) network-enabled, value-creation logic; and
> 3) user-value functions.

List of Acronyms

AEGIS – Advanced Electronic Guided Interceptor System

AFMSS – Air Force Mission Support System

AFSPACECOM – Air Force Space Command

ALERT – Attack and Launch Early Reporting to Theater

ATM – Asynchronous Transfer Mode

AWACS – Airborne Warning and Control System

AWE – Advanced Warfighting Experiment

BDA – Battlespace Damage Assessment

CCRP – C4ISR Cooperative Research Program

CD – Compact Disk

CEC – Cooperative Engagement Capability

CEP – Cooperative Engagement Processor

ConOps – Concept of Operations

COP – Common Operational Picture